AIRS Version 5 Release
Level 2 Standard Product
Cloud-Cleared Radiances

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Error Estimates and Suggested Quality Control for AIRS Clear Column Radiances

Overview

The AIRS Clear Column Radiances require quality control for optimal use in data assimilation or validation studies. The single case dependent Qual_CCR_flag, which has Version 4 heritage, is NOT adequate, as it provides no distinction among channels. The Version 5 methodology used to generate clear column radiance error estimates was designed to accommodate the use of AIRS clear column radiances $\hat{R}_i$ for data assimilation purposes. The most important channels for radiance assimilation purposes are in the temperature sounding spectral regions 650 cm^{-1} – 750 cm^{-1} and 2180 cm^{-1} – 2395 cm^{-1}, and the error estimate methodology was designed for use in these spectral regions only. In Version 5, error estimates are provided in each retrieval for each channel for completeness. This information is provided in the DAAC "L2 Standard Cloud-Cleared Radiance Product" dataset, short name of AIRI2CCF. Two recipes for quality control, based on use of these error estimates, are discussed in the following sections. Technique 1 requires modest numerical calculations using words written out in AIRI2CCF but is applicable to all channels in the temperature sounding regions given above. Technique 2 is simpler but is applicable only for Version 5 clear column radiance error estimates in the 650 cm^{-1} – 750 cm^{-1} spectral region. The Version 5 clear column radiance error estimates are probably not useful in other spectral regions.

The clear column radiance $\hat{R}_i$

The clear column radiance for channel i, $\hat{R}_i$, is a derived quantity obtained as part of the Version 5 physical retrieval process, and has an associated case and channel dependent error estimate $\delta\hat{R}_i$. Values of $\hat{R}_i$ and $\delta\hat{R}_i$ are generated for all operable AIRS channels in those cases where a successful IR/MW retrieval is produced (roughly 80% of all cases). $\hat{R}_i$ and $\delta\hat{R}_i$ are the second and third words in the full swath cloud cleared radiance data field. They are called radiances and radiance_err respectively.

The AIRS/AMSU Version 5 retrieval algorithm performs one retrieval per AMSU Field of Regard (FOR), which contains 9 AIRS Fields of View (FOV's). Each AIRS FOV (j = 1,9) within the AMSU FOR has an observed radiance for each channel i, $R_{i,j}$. The observations $R_{i,j}$ are potentially affected by clouds in FOV j. $\hat{R}_i$ represents the best estimate of what the AIRS channel i radiance, averaged over the 9 FOV's in the AMSU FOR, would have been if all FOV's were completely cloud free.

$\hat{R}_i$ is obtained according to

$$\hat{R}_i = \bar{R}_i + \sum_{j=1}^{9} \eta_j \left(\bar{R}_i - R_{i,j} \right) \tag{1}$$

where $\bar{R}_i$ is the average value of $R_{i,j}$ over the 9 FOV's and η_j (j=1,9) is a derived vector for each FOR obtained as part of the retrieval process. The physical retrieval process finds the surface and atmospheric state X_ℓ such that radiances computed using X_ℓ best match the derived clear column radiances $\hat{R}_i$. $\hat{R}_i$ can also be used as input for data assimilation purposes. For optimal results, data assimilation should account for the uncertainties in $\hat{R}_i$, $\delta\hat{R}_i$, or at least take into account $\delta\hat{R}_i$ as quality control to decide which values of $\hat{R}_i$ should be assimilated on a case-by-case basis.

Contributions to errors in $\hat{R}_i$

The following sections describe the factors that contribute to noise in the cloud-cleared radiances. $\hat{R}_i$ has two sources of noise. The first source of noise results from instrumental measurement error of channel i, $NE\Delta N_i$, and the second source of noise arises from errors in the vector η_j.

The effect of the channel noise amplification factor $\tilde{A}$ on instrumental noise

If all values of η_j used in equation (1) were perfect, then the error in $\hat{R}_i$ would be

$$\delta\hat{R}_i^{per} = \tilde{A}\ NE\Delta N_i \tag{2}$$

where $\tilde{A}$ is the channel noise amplification factor, resulting from the taking a linear combination of observations in the 9 fields of view to obtain $\hat{R}_i$, each with random noise $NE\Delta N_i$. In general, if one constructs a measurement by taking a linear combination of different measurements with the same random noise component $NE\Delta N_i$, $\bar{R}_i = \sum a_{i,j} R_{i,j}$, then the effective noise in $\bar{R}_i$ is given by $\sqrt{\sum a_{i,j}{}^2}\ NE\Delta N_i$.

To help visualize this phenomenon, consider the case of two measurements $R_{i,1}$ and $R_{i,2}$, each with the same random noise $NE\Delta N_i$. If $\hat{R}_i$ were obtained from the two observations according to $\hat{R}_i = \left(2R_{i,1} - R_{i,2}\right)$, which corresponds to an extrapolation of the observed radiances to give $\hat{R}_i$, then $\tilde{A}$ would be equal to $\sqrt{2^2 + 1^2} = \sqrt{5}$. This indicates that extrapolation of radiances in the FOR to give $\hat{R}_i$ increases the effective noise of the measurement. If, on the other hand, $\hat{R}_i$ were given by $\left(\frac{R_{i,1} + R_{i,2}}{2}\right)$, then $\tilde{A}$ would be equal to $\sqrt{(1/2)^2 + (1/2)^2} = 1/\sqrt{2}$. This results in a noise reduction obtained by averaging the observed radiances in the two FOV's.

In Version 5, $\hat{R}_i$ is obtained by taking a linear combination of 9 values of $R_{i,j}$ according to equation 1. It can be shown that the appropriate value of $\tilde{A}$ is given by

$$\tilde{A} = \left[\left(\sum_{j=1}^{9} \frac{1}{9} \cdot \left(1 + \sum_{j=1}^{9} \eta_j'\right) - \eta_j\right)^2\right]^{1/2} \tag{3}$$

Equation 1 shows that $\hat{R}_i = \bar{R}_i$ if all η_j's are zero. This situation corresponds to a case where the clear column radiance is obtained by averaging the radiances in all 9 FOV's. Equation 3 reduces to $\tilde{A} = 1/3$ when all η_j's are zero. In general, this is not the case and $\tilde{A}$ is usually greater than 1, depending on the extent of cloud clearing (extrapolation) performed in the FOR.

$\tilde{A}$ is in principle channel independent because it arises only from the linear combination of radiances used to construct $\hat{R}_i$. Some channels are only sensitive to the atmosphere at pressures lower than the cloud top pressure (altitudes higher than the cloud top height), and these case dependent channels do not "see" the clouds. The retrieval algorithm determines which channels do not "see" clouds, and for these channels sets $\hat{R}_i = \bar{R}_i$ and also sets $\tilde{A} = \tilde{A}^{CLR} = 1/3$ for such channels. Equation 3 is used for $\tilde{A}_i$ for all other channels.

Additional noise effects on $\hat{R}_i$ resulting from errors in the vector η_j

In general, the largest source of noise in $\hat{R}_i$ is a result of errors in the vector η_j. Errors in $\hat{R}_i$ resulting from errors in η_j tend to be systematic in a given FOR and will be correlated from channel to channel. The reverse is true for errors arising from the amplification of channel measurement noise, which is random between channels. In Version 5, we express $\delta\hat{R}_i$ as the sum of the errors arising from both sources,

$$\delta\hat{R}_i = \delta\hat{R}_i^{per} + \delta\hat{R}_i^{\delta\eta} \tag{4}$$

$\delta\hat{R}_i^{\delta\eta}$ is generated in the Version 5 retrieval algorithm according to

$$\delta\hat{R}_i^{\delta\eta} = \sum_{\ell} M_{i\ell}\,\delta X_{\ell} \tag{5}$$

where δX_{ℓ} is the error estimate for geophysical parameter X_{ℓ} obtained by the physical retrieval for the FOR, and $M_{i\ell}$ is an empirical channel dependent matrix generated once and for all. In Version 5, uncertainties of 7 geophysical parameters are included in the generation of $\delta\hat{R}_i^{dn}$. The first 6 terms correspond to predicted errors of tropospheric temperatures at 6 different pressures, and the 7th term in the sum is the predicted percentage error of total precipitable water.

The clear column brightness temperature error $\delta\hat{\Theta}_i$

Clear column radiances and their associated error estimates are written out in radiance units (mW/m^2-sr-cm^{-1}). It is more convenient, however, to think in terms of clear column brightness temperatures $\hat{\Theta}_i$, and their error estimates $\delta\hat{\Theta}_i$, both given in K. $\hat{\Theta}_i$ is the equivalent blackbody temperature of $\hat{R}_i$, or put another way, a blackbody with temperature $\hat{\Theta}_i$ would produce the radiance $\hat{R}_i$ at frequency ν_i. The radiance a blackbody would generate at temperature T and frequency ν_i is given by

$$R = B_{\nu_i}(T) = 1.19\text{x}10^{-5}\,\nu_i^{\,3} \,/\left(e^{1.439\nu_i/T} - 1\right) = c_1\nu_i^{\,3} \,/\left(e^{c_2\nu_i/T} - 1\right) \tag{6}$$

where ν_i is given in cm^{-1}. The associated clear column brightness temperature $\hat{\Theta}_i$ corresponding to clear column radiance $\hat{R}_i$ is given by

$$\hat{\Theta}_i = c_2\nu_i \,/\, \ell n\left(c_1\nu_i^{\,3} / \hat{R}_i + 1\right). \tag{7}$$

Given $\hat{R}_i$ and $\delta\hat{R}_i$, and the corresponding value of $\hat{\Theta}_i$, $\delta\hat{\Theta}_i$ is evaluated according to

$$\delta\hat{\Theta}_i = \left(\frac{dB_{\nu_i}}{dT}\right)_{\hat{\Theta}_i}^{-1} \delta\hat{R}_i \tag{8a}$$

$$= \left(e^{c_2\nu_i/\hat{\Theta}_i} - 1\right)^2 \hat{\Theta}_i^{\,2} \,/\, c_1 c_2 \nu_i^{\,4} e^{(c_2\nu_i/\hat{\Theta}_i)}\,\delta\hat{R}_i \tag{8b}$$

Figure 1a shows the spatial distribution of the differences of $\hat{\Theta}_i$ (K) derived for the AIRS channel at 724.52 cm^{-1}, from those computed using the collocated ECMWF analysis surface and atmospheric state as truth, for all cases in which a successful Version 5 IR/MW retrieval was produced. There is one granule of data missing over central Africa and data gaps exist between orbits. Otherwise, successful Version 5 retrievals are produced in most locations except under essentially overcast conditions.

The 724.52 cm^{-1} channel is located between CO_2 absorption lines, corresponding to a local maximum in frequency of the spectral brightness temperature, and is primarily sensitive to atmospheric temperatures in the vicinity of 600 mb. There is a substantial negative bias (-0.67K) between $\hat{\Theta}_i$ and $\hat{\Theta}_i$ truth due to insufficient cloud clearing in areas where successful combined IR microwave retrievals were produced, but were of poor quality beneath the cloud level. Figure 1a contains no quality control other than excluding all cases for which no clear column radiances were produced. Figure 1b shows the spatial distribution of the brightness temperature error estimates for this channel (error estimates are all positive), and Figure 1d shows the difference between the error estimates and the absolute value of the "error". The spatial correlation of the predicted and observed errors is very good, with a value of 0.68. The magnitudes of the observed and predicted errors are also in good agreement. Some of the disagreement is a result of errors in $\hat{\Theta}_i^{\text{truth}}$ arising from errors in the ECMWF analysis used as truth.

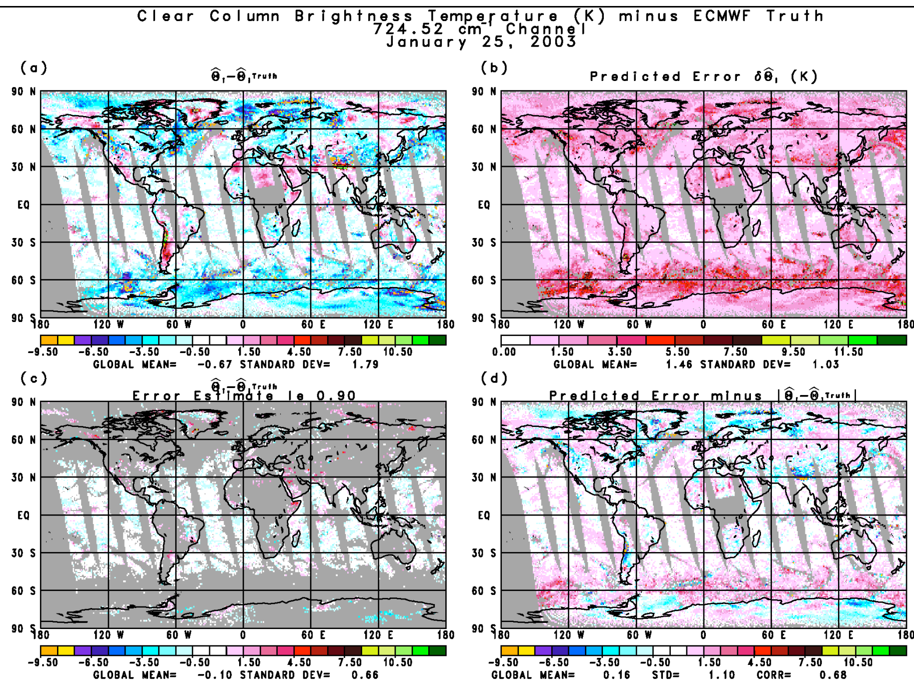

Figure 1: Spatial distribution of the differences of $\hat{\Theta}_i$ derived from the AIRS channel at 724.52 cm^{-1}, from those computed using the collocated ECMWF analysis surface and atmospheric state for successful V5 IR/MW retrievals. Panel 1a shows cases with no quality control. Panel 1b shows brightness temperature error estimates for the channel. Panel 1c shows subset of brightness temperature errors less than 0.9 K. Panel 1d shows difference between error estimates and the absolute value of the "error".

Approaches for Quality Control (QC) for $\hat{R}_i$

Different channels are sensitive, by varying amounts, to clouds at different pressures. Therefore, $\delta\hat{\Theta}_i$ is both channel and case dependent. Even if significant cloud clearing errors exist for a given case, channels that have little or no sensitivity to the clouds in that case would have very accurate values of $\hat{R}_i$. Under some conditions, all channels have very accurate values of $\hat{R}_i$. Therefore, in principle, each channel should have its own case dependent QC flag indicating whether the cloud-cleared radiance $\hat{R}_i$ is of sufficient accuracy for use. The Version 5 infrastructure for QC flags is the same as that for Version 4, and contains only a single case dependent QC flag for cloud-cleared radiances as a whole. This QC flag is the first word in the full swath cloud-cleared radiance data field, and is called Qual_CC_Rad. This historical one size fits all radiance QC flag should not be used for any purpose, and certainly not for data assimilation purposes. The following sections show two different approaches for Quality Control of $\hat{R}_i$.

QC Technique 1

The predicted clear column brightness temperature error $\delta\hat{\Theta}_i$ can be used directly as quality control for the clear column radiance $\hat{R}_i$ on a case-by-case basis. Figure 1c shows an example of the distribution of quality controlled clear column radiances, retaining only those cases in which $\delta\hat{\Theta}_i$ was less than or equal to a value of 0.9K, which is used here as a sample error estimate threshold for quality control. As in the rest of Figure 1, results are displayed in brightness temperature errors as compared to Θ_i^{truth}. The negative bias of $\hat{\Theta}_i$ compared to truth has been essentially eliminated, and the standard deviation of the quality controlled clear column radiance errors has been reduced from 1.75K to 0.66K, which is not significantly above the channel noise. Spatial coverage and accuracy over ocean is extremely good using a QC threshold of 0.9K. Raising (or lowering) the threshold would result in greater (lesser) spatial coverage with a larger (smaller) standard deviation of the errors.

Figure 2 shows the effect of using 0.9K as a QC threshold for $\delta\hat{\Theta}_i$ for all channels between 650 cm^{-1} and 750 cm^{-1}, based on global Version 5 results for January 25, 2003. The location of the channel at 724.52 cm^{-1}, whose results are shown in Figure 1, is indicated by the black dots in Figures 2a-2c.

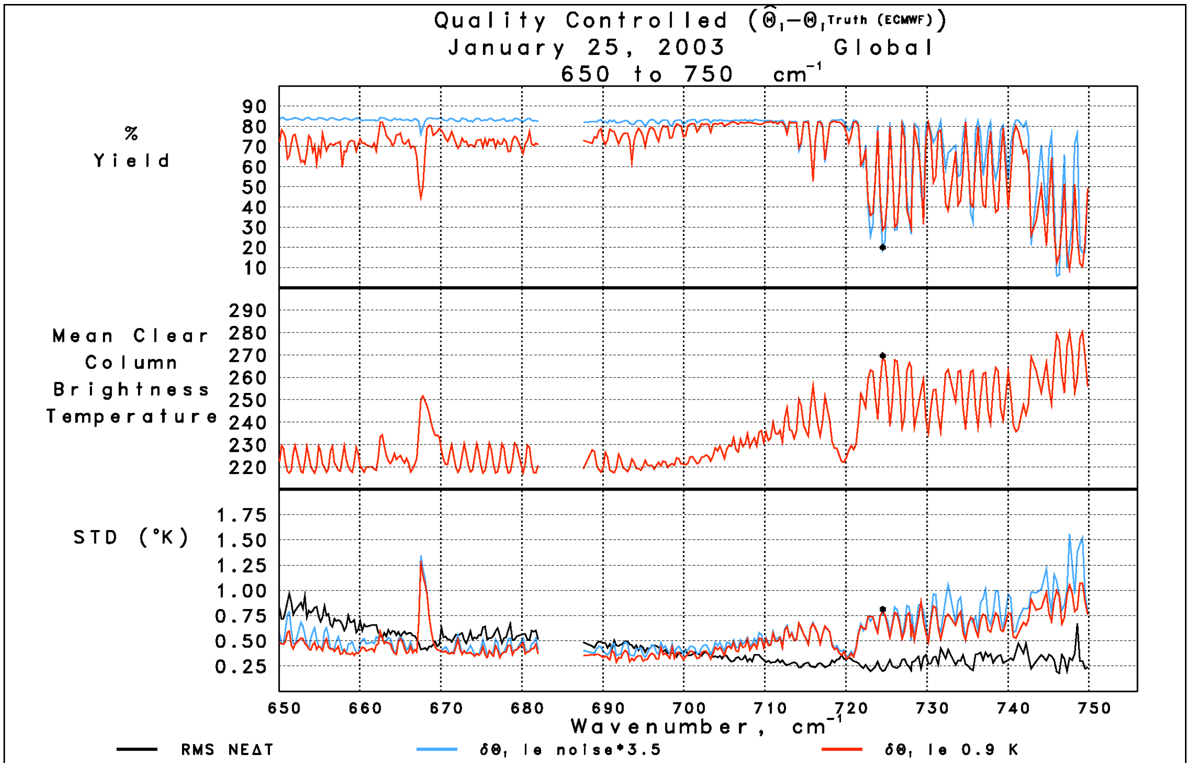

Figure 2: Effect of using 0.9 K as quality control threshold for $\delta\hat{\Theta}_i$ for all channels between 650 cm^{-1} and 750 cm^{-1}.
Top panel shows yield. Center panel shows mean clear column brightness temperature. Bottom panel shows the standard deviation of the quality-controlled values (red) and NEdT for channels (black).

Figure 2 top panel shows in red the percentage of all global FOV's in which $\hat{\Theta}_i$ was found acceptable using the 0.9K criterion for $\delta\hat{\Theta}_i$. The maximum possible percentage is given roughly by 82%, because in 18% of the cases, a successful IR/MW retrieval was not generated and $\hat{\Theta}_i$ was not produced.

Figure 2 middle panel shows the global mean clear column brightness temperatures for the 82% of cases in which $\hat{\Theta}_i$ was generated. Channels with $\nu < 710$ cm^{-1} are sensitive primarily to stratospheric temperatures above the clouds and, with one exception, have yields close to 80%. Percent yield decreases as channels see lower to the surface, indicated by increasingly higher values of $\hat{\Theta}_i$. Roughly 30% of the clear column radiances at
724 cm^{-1} were considered acceptable by the QC threshold $\delta\hat{\Theta}_i < 0.9$K.

Figure 2 bottom panel shows the standard deviation (STD) of quality-controlled values of $\left(\hat{\Theta}_i - \Theta_i^{\text{truth}}\right)$ in red, as well as the RMS channel noise NEΔT$_i$ evaluated at $\hat{\Theta}_i$ for all cases in black. Part of the differences between $\hat{\Theta}_i$ and Θ_i^{truth} comes from errors in η, part comes from the effect of channel noise, and part comes from errors in Θ_i^{truth}. The most opaque spectral region of the atmosphere occurs at 667 cm^{-1}. The spike in "errors" at 667 cm^{-1}, results from errors in the ECMWF truth at 1 mb. These errors in ECMWF "truth" also contribute to spuriously high values of $\delta\hat{\Theta}_i$ for this channel, resulting in a drop in the yield of quality-controlled values of $\hat{\Theta}_i$ at this frequency using 0.9K as a QC threshold. We will call use of a threshold in predicted clear column brightness temperature error for QC as QC Technique 1. It is apparent that quality controlled $\hat{\Theta}_i$ using QC Technique 1 have errors that are not appreciably larger than the instrumental noise of AIRS. The standard deviation of $\hat{\Theta}_i - \Theta_i^{truth}$ at 724 cm^{-1} for accepted cases is 0.75K, while the RMS value of instrument NEDT at that channel is 0.25K. The standard deviations of $\hat{\Theta}_i - \Theta_i^{truth}$ are actually lower than the instrument noise for stratospheric sounding channels, resulting from the averaging of the radiances in the 9 FOV's to obtain $\hat{\Theta}_i$.

QC Technique 2

There is an alternative simpler approach to quality control for $\hat{R}_i$ which avoids the need for use of equations 7 and 8. In this approach, one uses $\delta\hat{R}_i$ directly, and selects cases in which the ratio $\delta\hat{R}_i / NE\Delta N_i$ is less than a threshold value. The advantage of this approach is that both $\delta\hat{R}_i$ and $NE\Delta N_i$ are written out directly. $NE\Delta N_i$ is written out once per granule under the name NeN_L1B. On the other hand, this simplified approach ignores the fact that a given ratio of $\delta\hat{R}_i$ to $NE\Delta N_i$ contributes to larger errors in $\hat{\Theta}_i$ at low scene temperatures than at high scene temperatures. We will call the QC approach of using a threshold in the ratio of predicted clear column radiance error to channel noise as QC Technique 2. Figures 2a and 2c include analogous results of percent yield and standard deviation of $\hat{\Theta}_i - \Theta_i^{truth}$, shown in blue, if one accepts clear column radiances only if $\delta\hat{R}_i / NE\Delta N_i \le 3.5$. This ratio threshold is consistent with the ratio of the brightness temperature error threshold, 0.9K, to the RMS instrument $NE\Delta T$ at 724 cm^{-1}, which has a value of 0.25K.

Results using the two approaches for Quality Control are generally similar in the spectral region 650 cm^{-1} to 750 cm^{-1}. This spectral region, referred to as the longwave temperature sounding region, is the region commonly used for radiance assimilation. Yields are higher above 730 cm^{-1} using QC Technique 2 compared to QC Technique 1, as are the standard deviations of $\hat{\Theta}_i - \Theta_i^{truth}$. This is most likely a result of these channels being relatively noisier than those at lower frequencies.

Figure 3 is analogous to Figure 2, but for the spectral region 2175 cm^{-1} to 2400 cm^{-1}. This spectral region, like the region 650 cm^{-1} – 750 cm^{-1}, is very important for determining atmospheric temperature, and is also useful for radiance assimilation purposes. Results in this spectral interval are shown only for nighttime cases because the "truth" does not accurately account for effects of solar radiation reflected off the surface.

Figure 3

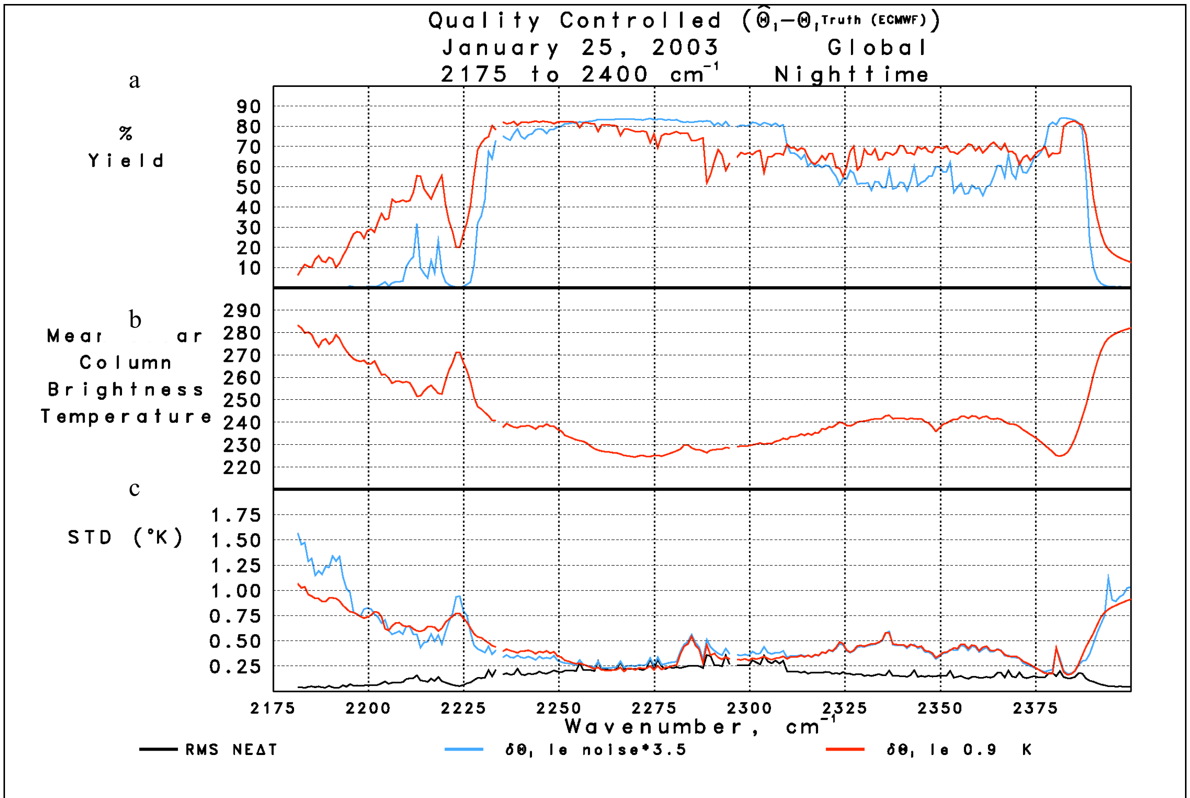

Figure 3: Effect of using 0.9 K as quality control threshold for $\delta\hat{\Theta}_i$ for all channels between 2175 cm^{-1} and 2400 cm^{-1}.

Top panel shows yield. Center panel shows mean clear column brightness temperature. Bottom panel shows the standard deviation of the quality-controlled values (red) and NEdT for channels (black).

There is a major difference between this shortwave temperature sounding region and the previous longwave temperature sounding region from the clear column radiance error perspective. In the shortwave temperature sounding region, there is very large brightness temperature dependence to values of $\delta\hat{\Theta}_i$ and the corresponding ratio $\delta\hat{R}_i\ /\mathrm{NE}\Delta\mathrm{N}_i$. In this spectral region, values of $\delta\hat{\Theta}_i$ consistent with a given noise ratio are much smaller at larger values of $\hat{\Theta}_i$, and much larger at lower values of $\hat{\Theta}_i$. The analogous temperature dependence is relatively small in the longwave temperature sounding region.

Figure 3a shows that the percent yield using QC Technique 2, with a ratio threshold of 3.5 is very poor in spectral regions with high (> 250K) values of $\hat{\Theta}_i$. This is because a radiance error to noise threshold cutoff of 3.5 corresponds to a very small cutoff in brightness temperature errors at frequencies sensitive to (generally warm) mid-lower tropospheric temperatures, especially for the warmer cases. In addition to having a low yield, the Quality Controlled clear column brightness temperature errors using QC Technique 2 are poorer than those using QC Technique 1 at these frequencies. This may be a result of preferentially selecting the colder (polar?) cases based on the radiance ratio threshold.

Suggested Quality Control for Clear Column Radiances

The above results indicate that it is optimal to use QC Technique 1 for clear column radiance Quality Control. It is suggested to flag the clear column radiance as acceptable if $\delta\hat{\Theta}_i < 0.9\text{K}$. The user can utilize tighter or looser thresholds as they see fit. This approach works well in both the longwave and shortwave temperature sounding regions.

The simpler to use approach, QC Technique 2, performs reasonably well in the longwave temperature sounding region, and is adequate for use if that is the only spectral region of interest to the user. Under those conditions, it is suggested to flag the clear column radiance as acceptable if $\delta\hat{R}_i \,/\, NE\Delta N_i < 3.5$. This approach to QC is not advisable in the shortwave temperature sounding region.